CLAIMS

What is claimed is:

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1. A micro-lens built-in vertical cavity surface emitting laser (VCSEL) comprising:

a substrate;

a lower reflector formed on the substrate;

an active layer formed on the lower reflector, generating light by a recombination of electrons and holes;

an upper reflector formed on the active layer comprising a lower reflectivity than that of the lower reflector;

a micro-lens disposed in a window region through which the laser beam is emitted;

a lens layer formed on the upper reflector with a transparent material transmitting a laser beam, the lens layer comprising the micro-lens;

an upper electrode formed above the upper reflector excluding the window region; and

a lower electrode formed underneath the substrate.

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2. The micro-lens built in VCSEL as recited in claim 1, wherein the VCSEL satisfies a following relationship:

$$f = R \times n1/(n2 - n1)$$

where f is a distance along an optical axis from a light generating region of the active layer to a vertex of the micro-lens, R is a radius of curvature of the micro-lens, n1 is an effective refractive index of a medium on an optical path between the light generating region and the lens layer, and n2 is a refractive index of a region towards which a light is emitted through the micro-lens.

3. The micro-lens built-in VCSEL as recited in claim 1, further comprising a high-resistance region between the upper and lower reflectors relatively close to the active

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layer, the high-resistance region having an aperture at a center thereof through which a current flows.

4. The micro-lens built-in VCSEL as recited in claim 1, wherein the lens layer is formed of a material comprising at least one of silicon and a III-V compound semiconductor, wherein the III-V compound semiconductor comprises one of indium phosphide (InP), gallium arsenide (GaAs), indium arsenide (InAs), gallium phosphide (GaP), indium gallium phosphide (InGaP), indium gallium arsenide (InGaAs), and aluminum gallium arsenide (AlGaAs), the material comprising a relatively large bandgap to a wavelength of the laser beam so as not to absorb the laser beam.

5. The micro-lens built-in VCSEL as recited in claim 1, wherein the micro-lens is formed by diffusion-limited etching.

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6. A micro-lens built-in vertical cavity surface emitting laser (VCSEL) comprising:

a substrate;

a lower reflector formed on the substrate;

an active layer formed on the lower reflector generating light by a recombination of electrons and holes;

an upper reflector formed on the active layer comprising a lower reflectivity than that of the lower reflector;

a micro-lens disposed in a window region through which the laser beam is emitted;

a lens layer formed on the upper reflector with a transparent material transmitting a laser beam, the lens layer comprising the micro-lens;

an upper electrode formed above the upper reflector excluding the window region; and

a lower electrode formed underneath the substrate,

wherein the window region comprises a maximum width smaller than a size of light generated in the active layer emitted towards the window region, satisfying a Fraunhofer

diffraction condition, where the Fraunhofer diffraction condition occurring in the window region is offset by a focusing power of the micro-lens.

7. The micro-lens built-in VCSEL as recited in claim 6, wherein the maximum width of the window region D and a focal length f of the micro-lens satisfy a relation:

$$D = \sqrt{2 \times 1.22\lambda f}$$

where λ is a wavelength of the laser beam emitted from the VCSEL.

8. The micro-lens built-in VCSEL as recited in claim 6, further comprising a high-resistance region between the upper and lower reflectors, relatively close to the active layer, the high-resistance region comprising an aperture at a center thereof through which a current flows, the aperture of the high-resistance region comprising a maximum width greater than or approximately equal to the maximum width of the window region.

9. The micro-lens built-in VCSEL as recited in claim 7, further comprising a high-resistance region between the upper and lower reflectors, relatively close to the active layer, the high-resistance region comprising an aperture at a center thereof through which a current flows, the aperture of the high-resistance region comprising a maximum width greater than or approximately equal to the maximum width of the window region.

10. The micro-lens built-in VCSEL as recited in claim 4, wherein the lens layer is formed of a material comprising at least one of silicon and a III-V compound semiconductor, wherein the III-V compound semiconductor comprises one of indium phosphide (InP), gallium arsenide (GaAs), indium arsenide (InAs), gallium phosphide (GaP), indium gallium phosphide (InGaP), indium gallium arsenide (InGaAs), and aluminum gallium arsenide (AlGaAs), the material comprising a relatively large bandgap to a wavelength of the laser beam so as not to absorb the laser beam.

11. The micro-lens built-in VCSEL as recited in claim 4, wherein the micro-lens is formed by diffusion-limited etching.

12. A micro-lens built-in vertical cavity surface emitting laser (VCSEL) comprising:

a micro-lens disposed in a window region through which a laser beam is emitted;

a substrate comprising a transparent material transmitting the laser beam, the substrate comprising the micro-lens;

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a lower reflector formed on the substrate;

an active layer formed on the lower reflector, generating light by recombination of electrons and holes;

an upper reflector formed on the active layer comprising a higher reflectivity than that of the lower reflector;

an upper electrode formed on the upper reflector; and

a lower electrode formed on a portion of the substrate excluding the window region through which the laser beam is emitted.

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13. The micro-lens built in VCSEL as recited in claim 12, wherein the VCSEL satisfies a following relationship:

$$f = R \times n1/(n2 - n1)$$

where f is a distance along an optical axis from a light generating region of the active layer to a vertex of the micro-lens, R is a radius of curvature of the micro-lens, n1 is an effective refractive index of a medium on an optical path between the light generating region and the lens layer, and n2 is a refractive index of a region towards which a light is emitted through the micro-lens.

14. The micro-lens built-in VCSEL as recited in claim 12, further comprising a high-resistance region between the upper and lower reflectors relatively close to the active layer, the high-resistance region having an aperture at a center thereof through which a current flows.

15. The micro-lens built-in VCSEL as recited in claim 12, wherein the lens layer is formed of a material comprising at least one of silicon and a III-V compound semiconductor,

C' cont'd wherein the III-V compound semiconductor comprises one of indium phosphide (InP), gallium arsenide (GaAs), indium arsenide (InAs), gallium phosphide (GaP), indium gallium phosphide (InGaP), indium gallium arsenide (InGaAs), and aluminum gallium arsenide (AlGaAs), the material comprising a relatively large bandgap to a wavelength of the laser beam so as not to absorb the laser beam.

16. The micro-lens built-in VCSEL as recited in claim 12, wherein the micro-lens is formed by diffusion-limited etching.

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17. A micro-lens built-in vertical cavity surface emitting laser (VCSEL) comprising:

a micro-lens disposed in a window region through which a laser beam is emitted;

a substrate comprising a transparent material transmitting the laser beam, the substrate comprising the micro-lens;

a lower reflector formed on the substrate;

an active layer formed on the lower reflector, generating light by recombination of electrons and holes;

an upper reflector formed on the active layer comprising a higher reflectivity than that of the lower reflector;

an upper electrode formed on the upper reflector; and

a lower electrode formed on a portion of the substrate excluding the window region through which the laser beam is emitted,

wherein the window region comprises a maximum width smaller than a size of the light generated in the active layer and emitted towards the window region, satisfying a Fraunhofer diffraction condition, where the Fraunhofer diffraction condition occurring in the window region is offset by a focusing power of the micro-lens.

sub a cont > 18. The micro-lens built-in VCSEL as recited in claim 17, wherein the maximum width of the window region D and a focal length f of the micro-lens satisfy a relation:

$$D = \sqrt{2 \times 1.22 \lambda f}$$

where λ is a wavelength of the laser beam emitted from the VCSEL.

c' cntd 19. The micro-lens built-in VCSEL as recited in claim 17, further comprising a high-resistance region between the upper and lower reflectors positioned relatively close to the active layer, the high-resistance region comprising an aperture at a center thereof through which a current flows, where the aperture of the high-resistance region comprises a maximum width greater than or approximately equal to the maximum width of the window region.

20. The micro-lens built-in VCSEL as recited in claim 18, further comprising a high-resistance region between the upper and lower reflectors positioned relatively close to the active layer, the high-resistance region comprising an aperture at a center thereof through which a current flows, where the aperture of the high-resistance region comprises a maximum width greater than or approximately equal to the maximum width of the window region.

21. The micro-lens built-in VCSEL as recited in claim 17, wherein the lens layer is formed of a material comprising at least one of silicon and a III-V compound semiconductor, wherein the III-V compound semiconductor comprises one of indium phosphide (InP), gallium arsenide (GaAs), indium arsenide (InAs), gallium phosphide (GaP), indium gallium phosphide (InGaP), indium gallium arsenide (InGaAs), and aluminum gallium arsenide (AlGaAs), the material comprising a relatively large bandgap to a wavelength of the laser beam so as not to absorb the laser beam.

22. The micro-lens built-in VCSEL as recited in claim 18, wherein the micro-lens is formed by diffusion-limited etching.

~~23. A micro-lens built-in vertical cavity surface emitting laser (VCSEL), comprising:~~

~~a micro-lens integrally formed on a laser beam emitting surface of the VCSEL emitting a parallel light beam.~~

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24. The micro-lens built-in VCSEL as recited in claim 23, further comprising:

a substrate;

a lower electrode formed underneath the substrate;

a lower reflector;

an active layer comprising a light generating region;

an upper reflector comprising a relatively lower reflectivity than that of the lower reflector;

a lens layer formed on the upper reflector, wherein the micro-lens is formed in a window region of the lens layer through which the light beam is condensed and emitted; and

an upper electrode formed on a portion of the lens layer excluding the window region, wherein the window region is defined by the upper electrode and the micro-lens.

25. The micro-lens built-in VCSEL as recited in claim 24, wherein the first focal point of the micro-lens is positioned in the light generating region of the active layer, so that the light beam generated in a narrow light generating region is incident on and condensed by the micro-lens, and is emitted as the parallel light beam.

26. The micro-lens built-in VCSEL as recited in claim 24, further comprising:

a high-resistance region between the upper and lower reflectors relatively close to the active layer, the high-resistance region having an aperture at a center thereof through which a current flows comprising a maximum width greater than or approximately equal to the maximum width of the window region.

27. The micro-lens built-in VCSEL as recited in claim 26, wherein the aperture is small where the current applied through the upper electrode passes a region on the active layer and the light beam is generated in a dot-sized region of the active layer.

28. The micro-lens built-in VCSEL as recited in claim 23, wherein the micro-lens lies along a central optical axis of the light beam emitted from the VCSEL.

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29. The micro-lens built-in VCSEL as recited in claim 24, wherein the lower reflector, the active layer, and the upper reflector are sequentially stacked on the substrate.

30. The micro-lens built-in VCSEL as recited in claim 24, wherein the substrate is formed of a semiconductor material comprising n-doped gallium arsenide (GaAs), aluminum gallium arsenide (AlGaAs), indium arsenide (InAs), indium phosphide (InP), gallium phosphide (GaP), indium gallium phosphide (InGaP), indium gallium arsenide (InGaAs), or gallium phosphide (GaP), the material comprising a relatively large bandgap to a wavelength of the laser beam so as not to absorb the laser beam.

31. The micro-lens built-in VCSEL as recited in claim 24, wherein the lower reflector and the upper reflector are formed of alternating semiconductor compounds comprising different refractive indexes.

32. The micro-lens built-in VCSEL as recited in claim 24, wherein the substrate is doped with n-type impurities, the lower reflector is doped with the same n-type impurities and the upper reflector is doped with p-type impurities.

33. The micro-lens built-in VCSEL as recited in claim 24, wherein the active layer is formed of GaAs, AlGaAs, InGaAs, InGaP and/or AlGaAsP according to a wavelength of the light beam.

34. The micro-lens built-in VCSEL as recited in claim 24, further comprising:

a high-resistance region comprising an aperture at a center thereof through which current applied through the upper electrode flows and high-resistance region is formed by implantations of ions or by selective oxidation in a region of the upper reflector.

35. The micro-lens built-in VCSEL as recited in claim 24, wherein the lens layer comprises a thickness of several micrometers and is formed of a material having a relatively wide bandgap to a wavelength of the light beam generated from the VCSEL.

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36. The micro-lens built-in VCSEL as recited in claim 23, wherein the micro-lens comprises a convex surface formed by diffusion-limited etching.

37. The micro-lens built-in VCSEL as recited in claim 24, wherein the upper electrode is formed on the lens layer or between the upper reflector and the lens layer.

38. The micro-lens built-in VCSEL as recited in claim 24, wherein a distance along an optical axis from the light generating region to a vertex of the micro-lens is equal to a focal length of the micro-lens.

39. The micro-lens built in VCSEL as recited in claim 38, wherein the VCSEL satisfies a following relationship:

$$f = R \times n1/(n2 - n1)$$

where f is a distance along an optical axis from the light generating region to the vertex of the micro-lens, R is a radius of curvature of the micro-lens, $n1$ is an effective refractive index of a medium on an optical path between the light generating region and the lens layer, and $n2$ is a refractive index of a region toward which the light beam is emitted through the micro-lens.

40. The micro-lens built in VCSEL as recited in claim 38, wherein the VCSEL satisfies a following relationship:

$$n1/S1 + n2/S2 = (n2 - n1)/R$$

where S1 is a distance from the light generating region of the active layer to a vertex of the micro-lens on the optical axis, S2 is a distance from the vertex of the micro-lens to a second focal point of the micro-lens, n1 is an effective refractive index of the medium from the upper reflector and the lens layer, and n2 is a refractive index of a region toward which the light beam emitted through the micro-lens travels.

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41. The micro-lens built in VCSEL as recited in claim 24, wherein as a forward biased current is applied to the micro-lens built-in VCSEL through the upper and lower electrodes, the light beam comprising a particular wavelength through laser oscillation is transmitted through the upper reflector and the lens layer and is condensed by the micro-lens and emitted as the parallel laser beam.

42. The micro-lens built in VCSEL as recited in claim 23, wherein the VCSEL is a top-emitting type VCSEL.

43. The micro-lens built-in VCSEL as recited in claim 23, further comprising:

a substrate, wherein the micro-lens is formed in the window region of the substrate through which the light beam is condensed and emitted;

a lower reflector;

an active layer comprising a light generating region;

an upper reflector comprising a higher reflectivity than that of the lower reflector;

a lower electrode formed underneath the substrate excluding a window region through which the light beam is emitted; and

an upper electrode formed on the upper reflector, wherein the window region is defined by the lower electrode and the micro-lens.

44. The micro-lens built-in VCSEL as recited in claim 43, wherein a first focal point of the micro-lens is positioned in the light generating region of the active layer, where the light beam generated in a narrow light generating region is incident on and condensed by the micro-lens, and is emitted as the parallel light beam.

45. The micro-lens built-in VCSEL as recited in claim 43, further comprising:

a high-resistance region between the upper and lower reflectors relatively close to the active layer, the high-resistance region comprising an aperture at a center thereof

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through which a current flows comprising a maximum width greater than or approximately equal to the maximum width of the window region.

46. The micro-lens built-in VCSEL as recited in claim 43, wherein the lower reflector, the active layer, and the upper reflector are sequentially stacked on the substrate.

47. The micro-lens built-in VCSEL as recited in claim 43, wherein when a number of stacked layers of the lower reflector is smaller than that of the upper reflector, the reflectivity of the lower reflector is lower than that of the upper reflector and most of the laser beam is emitted through the lower reflector.

48. The micro-lens built-in VCSEL as recited in claim 43, wherein the substrate is formed of a semiconductor material comprising n-doped gallium arsenide (GaAs), aluminum gallium arsenide (AlGaAs), indium arsenide (InAs), indium phosphide (InP), gallium phosphide (GaP), indium gallium phosphide (InGaP), indium gallium arsenide (InGaAs), or gallium phosphide (GaP).

49. The micro-lens built-in VCSEL as recited in claim 43, wherein the lower reflector and the upper reflector are formed of alternating semiconductor compounds comprising different refractive indexes.

50. The micro-lens built-in VCSEL as recited in claim 43, wherein the substrate comprises a material having a relatively wide bandgap compared to a wavelength of the light beam generated from the VCSEL, so as not to absorb, but transmit the laser beam incident from the lower reflector.

51. The micro-lens built in VCSEL as recited in claim 43, wherein the VCSEL satisfies a following relationship:

$$f' = R' \times n1'/(n2' - n1')$$

C1 contd

where R′ is a radius of curvature of the micro-lens, n1′ is a effective refractive index of a medium along an optical path between the light generating region of the active layer and the micro-lens, and n2′ is a refractive index of a region toward which the light beam emits through the micro-lens, f′ is a distance from the light generating region to a vertex of the micro-lens along the optical axis.

52. The micro-lens built in VCSEL as recited in claim 43, wherein as a forward biased current is applied to the micro-lens built in VCSEL through the upper and lower electrodes, a laser beam comprising a particular wavelength through laser oscillation is transmitted through the lower reflector and the substrate and is condensed by the micro-lens and emitted as the parallel laser beam.

53. The micro-lens built in VCSEL as recited in claim 43, wherein the VCSEL is a bottom-emitting type VCSEL.

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~~54. The micro-lens built-in VCSEL as recited in claim 23, further comprising:~~

~~a substrate;~~

~~a lower electrode formed underneath the substrate;~~

~~a lower reflector;~~

~~an active layer comprising a light generating region;~~

~~an upper reflector comprising a relatively lower reflectivity than that of the lower reflector;~~

~~a lens layer formed on the upper reflector, wherein the micro-lens is formed in a window region of the lens layer through which the light beam is condensed and emitted; and~~

~~an upper electrode formed on a portion of the lens layer excluding the window region, wherein the window region comprises a diameter satisfying a Fraunhofer diffraction condition and is defined by the upper electrode and the micro-lens.~~

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55. The micro-lens built in VCSEL as recited in claim 54, wherein the window region comprises a maximum width smaller than a size of the light beam generated in the active layer emitted towards the window region.

56. The micro-lens built in VCSEL as recited in claim 54, wherein the Fraunhofer diffraction condition of the window is offset by a focusing power of the micro-lens so that a parallel laser beam is emitted through the micro-lens.

57. The micro-lens built in VCSEL as recited in claim 56, wherein the diameter D of the window and a focal length f of the micro-lens satisfy a following relationship:

$$D = \sqrt{2 \times 1.22 \lambda f}$$

where λ is a wavelength of the light beam emitted from the VCSEL.

58. The micro-lens built-in VCSEL as recited in claim 54, further comprising a high-resistance region between the upper and lower reflectors relatively close to the active layer, the high-resistance region comprises an aperture at the center thereof through which a current flows.

59. The micro-lens built in VCSEL as recited in claim 58, wherein the diameter of the window is smaller than or approximately equal to a diameter of the aperture of the high-resistance region.

60. The micro-lens built in VCSEL as recited in claim 54, wherein the window and the micro-lens are positioned on a same plane.

61. The micro-lens built in VCSEL as recited in claim 54, wherein the Fraunhofer diffraction condition satisfies a following relationship:

$$N_f = \frac{D^2}{\lambda d} << 1$$

C1 contd

where N_f is a Fresnel number, λ is a wavelength of the light beam emitted from the VCSEL, D is the diameter of the window, and *d* is a distance from the window to an observing plane, which is one focal point of the micro-lens.

62. The micro-lens built in VCSEL as recited in claim 54, wherein the micro-lens is positioned in front or behind the window or the micro-lens and the window are positioned on a same plane.

63. The micro-lens built in VCSEL as recited in claim 54, wherein when the micro-lens and the window are positioned on a same plane and only a 0^{th}-order diffracted beam comprising a high intensity is considered, a radius R_s of the 0^{th}-order diffracted beam satisfies a following relationship:

$$R_s = \frac{1.22\lambda d}{D}$$

where λ is a wavelength of the light beam emitted from the VCSEL, D is the diameter of the window, and d is a distance from the window to an observing plane.

64. The micro-lens built in VCSEL as recited in claim 54, wherein the VCSEL is a top-emitting type VCSEL.